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# THE FOURTH INTERNATIONAL CONFERENCE ON FRACTURE MECHANICS AND ENERGY

"Trends on Fracture and Environment"

November 26-29, 2018, Chlef, Algeria

# FINAL PROGRAM

November 2018

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| P6CM | **Elaboration and characterization of the mechanical behavior of an epoxy glass composite material**<br>**A. GHOUAOULA, A.VEFFA**<br>University Hassiba Benbouali, Chlef, Algeria |
| P7CM | **Mechanical and chemical behaviour of a composite material produced by uniaxial compression of a mixture of aluminium and alumina powders**<br>**S. DEHRIB, N. ZAZI, J.P. CHROPART**<br>University of Tizi- Ouzou, Mouloud Mammeri BP17RP, Tizi- Ouzou, Algeria |
| P8CM | **Macro scale modelisation of Chip formation in FRP composite machining**<br>**DJ. DJILALISALAH, M. MENDAS , M. HADJ MILOUD**<br>University HassibaBenbouali, Chlef, Algeria |
| P9CM | **Numerical model for repair patch optimization of 2024-T3 aluminum structures cracked in mixed mode under tensile loading**<br>**N.DEGHOUL, L. ERROUANE, Z. SEREIR**<br>University of Sciences and Technology of Oran Mohamed Boudiaf, Oran, Algeria |

**14:00--15:00 Poster session Energy and its Applications : Responsable : Prof. Naji Hassen, Loukarfi Larbi, Ali Khelil, Abdelkader Kheratt,**

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| P22EA | University of Sciences & Technology Mohamed Boudiaf, Oran ,Algérie<br>**Large-Eddy Simulation of Turbulent Jet Issued From Lobed Diffuser**<br>S. NECHAD, A. KHELIL, A. BENNIA, L. LOUKARFI<br>University Hassiba Benbouali LCEMSM , Algeria |
| P23EA | **Improvement of heat transfer by the interaction of a swirling jet impinging**<br>Y. BOUHAMIDI, A. KHELIL, M. BRAIKIA , S.NECHAD, L. LOUKARFI<br>University Hassiba Benbouali, LCEMSM , Algeria |
| P24EA | **Thermal characterization of a multi jet diffuser with lobes imbalances in temperature**<br>M. BRAIKIA, A. KHELIL, L. LOUKARFI, H. NAJI<br>University Hassiba Benbouali, LCEMSM , Algeria |
| P25EA | **An experimental investigation of interacting swirling multiple jets**<br>M. BRAIKIA, A. KHELIL, L. LOUKARFI, H. NAJI<br>University Hassiba Benbouali, LCEMSM , Algeria |
| P26EA | **Numerical simulation of a flow past a cubic and cylindrical tube by the large scale simulation method (LES)**<br>A.KHELIL, M. BADROUNI , M. BRAIKIA , I. BACHIR, A. ZERROUT<br>University Hassiba Benbouali, Chlef, LCEMSM , Algeria |
| P27EA | **FIRE PROTECTION DURABILITY OF INTUMESCENT COATINGS AFTER ACCELERATED AGING**<br>R. THABET, A. BENAROUS, L. MESQUITA<br>University Hassiba Benbouali, Chlef, LCEMSM , Algeria |
| P28EA | **Dynamic study of multiple jet with lobed diffusers**<br>W. MEDAOUAR, M. BRAIKIA, L. LOUKARFI, A. KHELIL, H, NAJI<br>University Hassiba Benbouali, Chlef, LCEMSM, Algeria |
| P29EA | **Pressure distribution analysis of plain journal bearing under hydrodynamic lubrication**<br>A. GHALEM, M. TAHAR ABBES, A.SAHLI<br>University Hassiba Benbouali, Chlef, Algeria |
| P30EA | **Study of the performance of the hydrodynamic bearing**<br>Mayas Saeed Abdullah ABDELWAHAB, Miloud TAHAR ABBES, Bassam Gamal Nasser MUTHANNA<br>University Hassiba Benbouali, Chlef, Algeria |
| P31EA | **Study of Synthetic Jet flow fields using Numerical Simulation**<br>**Z. ELKHALDI**, L. ADJLOUT, O. IMINE, P. DANČOVÁ ,AND T.VÍT<br>University of Sciences and Technology, M.B. Oran, Algeria |

## Numerical simulation of a flow past a cubic and cylindrical tube by the large scale simulation method (LES)

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**Abstract**:A numerical simulation in three dimensions has initiated the flow around an obstacle of a cylindrical or cubic geometrical shape in a laminar or turbulent regime. In this study, the large-scale numerical Simulation (LES) method using the fluent computer code has been used. This work allowed us to study the dynamic field velocity, pressure field and vorticity field. The results obtained for the two square and cylindrical obstacles for the laminar and turbulent regime were presented as curves and contours. For geometric configurations (cubic and cylindrical) the vorticity is greater in the turbulent regime than the laminar regime noting that the circulation zone is justified by a large depression and wider in the turbulent regime than in the laminar regime. For the cubic configuration, the circulation zone is larger than that in the cylindrical shape, so it is noted that the flow is more delayed in the cubic form than in the cylindrical form.

*Keywords:*Numerical simulation, Obstacle, LES and incompressible flow.

## FIRE PROTECTION DURABILITY OF INTUMESCENT COATINGS AFTER ACCELERATED AGING

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**Abstract**:The most common method of achieve the required fire resistance of structures and structural elements is using passive fire protection systems, being the intumescent coatings the fire protection material frequently used. This work presents a research study about the effects of aging on the fire protection performance of intumescent coatings. A commercial water based coating is submitted to an accelerated aging cycle, using a QUV accelerated weathering tester. These tests aim to simulate 10 years of the coating natural aging according to the European technical approval guideline (ETAG N° 018). The coating durability is tested comparing the fire protection efficiency of small steel samples submitted to a constant radiant heat flux exposure from a cone calorimeter as prescribed by the standard ISO 5660. In total, 28 tests were performed on intumescent coating protected steel specimens, in which 14 specimens were tested before the hydrothermal aging test and other 14 after accelerated aging. The experimental test results of the steel temperature evolution shows that increasing the intumescent dry film thickness, an increase of the fire resistance time is attained. After the accelerated aging cycles, the coating lose their ability to expand, resulting in an increase of the steel temperature of approximately 200 ºC, compared to the samples without aging.

*Keywords:*Fire protection, intumescent coating, accelerated aging, fire resistance durability.

## Dynamic study of multiple jet with lobed diffusers

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**Abstract**:In this work, we present an experimental and numerical study of the dynamic field of a multiple turbulent jet with lobed diffuser, applied to comfort in residential premises. The objective is to improve the efficiency of air diffusion in the lower cost occupation zone by passive means of flow control. The

# FIRE PROTECTION DURABILITY OF INTUMESCENT COATINGS AFTER ACCELERATED AGING

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**Abstract**: The most common method of achieve the required fire resistance of structures and structural elements is using passive fire protection systems, being the intumescent coatings the fire protection material frequently used. This work presents a research study about the effects of aging on the fire protection performance of intumescent coatings. A commercial water based coating is submitted to an accelerated aging cycle, using a QUV accelerated weathering tester. These tests aim to simulate 10 years of the coating natural aging according to the European technical approval guideline (ETAG N° 018). The coating durability is tested comparing the fire protection efficiency of small steel samples submitted to a constant radiant heat flux exposure from a cone calorimeter as prescribed by the standard ISO 5660. In total, 28 tests were performed on intumescent coating protected steel specimens, in which 14 specimens were tested before the hydrothermal aging test and other 14 after accelerated aging. The experimental test results of the steel temperature evolution shows that increasing the intumescent dry film thickness, an increase of the fire resistance time is attained. After the accelerated aging cycles, the coating lose their ability to expand, resulting in an increase of the steel temperature of approximately 200 ºC, compared to the samples without aging.

*Keywords:* Fire protection, intumescent coating, accelerated aging, fire resistance durability.

## Nomenclature

| | |
|---|---|
| DFT | Dry Film Thickness. |
| ds | Thickness of the steel plates. |
| Ai | Specimen i tested without protection. |
| Pi | Specimen i tested without aging. |
| Si | Specimen i tested after hydrothermal aging. |

## 1. Introduction

Passive fire protection materials insulate steel structures from the effects of the elevated temperatures that may be generated during fire. They can be divided into two types, non-reactive, of which the most common types are boards and sprays, and reactive, being intumescent coatings an example, [1]. These has been widely used as fire protection because it has such advantages as lightweight, attractive appearance and convenient construction.

The intumescent coatings, which usually are composed of organic components contained in a polymer matrix, are designed to decompose and expend when subjected to high temperatures so as to provide an insulating foamed char to protect the underlying substrate, [2]. Being different from traditional fire protection, intumescent coating goes through complicated physical and chemical reactions when exposed to fire, including time dependency of the thermal properties. Exposure to long term environmental conditions can cause intumescent coating to

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lose the reactive and swelling properties, thus reducing the effectiveness of the intumescent coating over time, [3].

In order to understand the aging mechanism of intumescent coating, Wang et al, [2], studied the degradation in fire protection performance of two types of intumescent coating after different cycles of accelerated hydrothermal aging test. In this experiment the authors use 56 specimens of intumescent coating protected steel, 16 of them were applied with type U-intumescent and the other with type A-intumescent coating. For the 40 type A-specimens, 20 were coated with 1 mm and the other 20 with 2 mm. The accelerated aging test related to this experiment adopted exposure condition Z1, as defined by ETAG N° 018, [4], each cycle of exposure is defined as 8 hour at (40±3) °C and (98±2) % of humidity than 16 h at (23±3) °C and (75±2) %RH. After the specimens were subjected to hydrothermal aging, they were placed in a furnace and exposed to fire. The furnace temperature was regulated according to the ISO 834 standard temperature-time curve. Each test was continued until the steel temperature reached 700 °C. The results showed that compared to specimens without hydrothermal aging, after 42 cycles of hydrothermal aging, the effective thermal conductivity of type-U and type A-intumescent coatings was 50% and 100% higher than that of the “fresh coating”, respectively. These increases in effective thermal conductivities resulted in increases in steel temperatures of up to 150 °C and 220 °C higher than the steel temperatures of the specimens without hydrothermal aging for the type-U and type-A-intumescent coatings specimens, respectively.

Passive fire protection (PFP) coatings are widely used in the offshore industry and increasingly so for onshore applications. However, there are concerns that the performance of PFP systems in a fire may have deteriorated because of weathering and/or that corrosion of the protected item may be taking place beneath the PFP systems. To see the effects of weathering, six epoxy intumescent PFP products and one cementations PFP product have been subjected to long term weathering at a maritime site, [5]. Roberts et al, presents the results in terms of resistance to weathering, corrosion and fire and suggest that, to have an effective resistance to weathering, most PFP coatings require proper preparation of the substrate (cleaning, priming, key coat, etc.), and closely controlled application within the specified environmental range (temperature, humidity). Moreover, a proper treatment of edge features to prevent the interface becoming a corrosion site and, when necessary, to provide resistance to jet fires. The PFP need also a resilient topcoat suitable for exposed duty, qualified as part of the fire testing and accelerated weathering programs, with timely renewal, in addition to adequate inspection, maintenance and repair.

The long term weathering effect on the intumescent coatings performance was also studied by several other authors, [6-9], both from the perspective of the final product behaviour and also analysing the weather degradation of its chemical components. Additionally, there is an uncertainty that older buildings continue to maintain the same fire safety level as when they were built. The study of Bilotta et al, [10], about the assessment of structural fire safety of existing buildings during a fire, considered different steel elements protected with intumescent coatings removed from a 30 years old building. The fire test results shows that after 30 years, the intumescent coating was poorly effective, having lower bond strength and thick DFT detach earlier during the fire tests.

The durability analysis of reactive coating systems must be assessed in order to obtain the Certification of Conformity and the CE marking. The procedure and the tests to be done are specified in the guideline for European technical approval of fire protective products, ETAG Nº 018 part 2, [4].

This paper presents an experimental study on the intumescent coating protected steel plates to provide some information about the impact of the hydrothermal aging on reduced fire protection performance of the intumescent coatings. Two series of tests have been conducted in a cone calorimeter. In series one, specimens with fresh dry coating were subjected to fire. In the second series, intumescent coating were tested after have been exposed to different cycles of accelerated hydrothermal aging.

## 2. Experimental setup

To assess the performance of a commercial water- based intumescent paints a set of experimental tests was performed in a cone calorimeter before and after have been exposed to an accelerated aging, see Table 1 and Table 2, respectively.

Table 1: Set of experimental tests without aging.

| specimens | Heat flux [$KW.m^{-2}$] | ds [mm] | Nominal DFT [µm] | X DFT [µm] | Initial Mass [g] |
|---|---|---|---|---|---|
| P1 | 75 | | | 483 | 1161.39 |
| P2 | 75 | 14 | 500 | 606 | 1120.28 |
| P3 | 35 | | | 628 | 1140.6 |
| P4 | 75 | | | 831 | 1155.73 |
| P5 | 75 | 14 | 1000 | 833 | 1127.6 |
| P6 | 35 | | | 1107 | 1122.2 |
| P7 | 75 | | | 751 | 407.9 |
| P8 | 75 | 5 | 500 | 705 | 414.9 |
| P9 | 35 | | | 589 | 449.6 |
| P10 | 75 | | | 1171 | 431.1 |
| P11 | 75 | 5 | 1000 | 1298 | 436.1 |
| P12 | 35 | | | 886 | 512.8 |
| P13 | 75 | 8 | 1000 | 943 | 639.7 |
| P14 | 35 | | | 602 | 650.2 |
| A1 | 75 | 14 | -- | -- | 1145.1 |
| | 35 | | | | |
| A2 | 75 | 8 | -- | -- | 636.7 |
| | 35 | | | | |
| A3 | 75 | 5 | -- | -- | 492.3 |
| | 35 | | | | |

--: The plates are not coated.

The steel plates are 100 mm squared and with 5, 8 and 14 mm thick, coated on one side with different dry film thicknesses (DFT) and tested in a cone calorimeter as prescribed by the standard ISO5660, [11], with two heat fluxes 35 and 75 $KW.m^{-2}$. Steel temperatures are measured by means of two thermocouples type k, welded to the plate surface on the heating side and on the opposite side.

The dry thickness was measured in 10 different points, the average value are presented. The distance between the sample surface and the cone heater remained unchanged, and defined initially as 40 mm. This means that with the increasing intumescence the top of the sample came closer to the cone surface.

To perform the coating accelerated aging test, a QUV Accelerated Weathering Tester were used. This equipment reproduces the damage or degradation caused by sunlight, rain and dew. The accelerated aging test was performed according to the European guideline ETAG N° 018, [4], using as a reference condition the weather exposure condition type Z1. In this exposure condition, each cycle of exposure stands as follows: 8 h at (40±3) °C and (98±2) %RH; then 16 h at (23±3) °C and (75±2) %RH. As the equipment is not able to maintain a continuous constant temperature of 23 ºC, the test setup was adopted as: 8 hours at 40 °C and 16 hours at 30 °C with condensing humidity in all cycles.

Accordingly to ETAG 018, 21 cycles of accelerated aging is equivalent to 10 years in service. Based on this correlation, 0 cycle, 4 cycles, 11 cycles and 42 cycles correspond to fresh coating, 2 years, 5 years and 20 years in service. The set of tests performed after the coating be submitted to this accelerated aging cycle is presented in the Table 2.

Table 2: Set of experimental tests with accelerated aging.

| specimens | Heat flux [kw.m$^{-2}$] | ds [mm] | Nom. DFT [µm] | X DFT [µm] | X DFT after aging [µm] | Initial Mass [g] |
|---|---|---|---|---|---|---|
| S1 | 75 | | | 625 | 647 | 1149.3 |
| S2 | 75 | 14 | 500 | 599 | 529 | 1134 |
| S3 | 35 | | | 436 | 362 | 1155.3 |
| S4 | 75 | | | 1359 | * | 1075.3 |
| S5 | 75 | 14 | 1000 | 733 | 708 | 1166.8 |
| S6 | 35 | | | 625 | 579 | 1158.7 |
| S7 | 75 | | | 795 | 778 | 423.9 |
| S8 | 75 | 5 | 500 | 712 | 696 | 407.2 |
| S9 | 35 | | | 689 | 694 | 398.57 |
| S10 | 75 | | | 1580 | 1990 | 429 |
| S11 | 75 | 5 | 1000 | 1312 | 1530 | 419.6 |
| S12 | 35 | | | 951 | 904 | 425.2 |
| S13 | 75 | 8 | 1000 | 947 | 994 | 650.4 |
| S14 | 35 | | | 752 | 695 | 648.8 |

*The protection was damage after the hydrothermal aging.

## 3. Experimental results.

### 3.1. Steel temperature evolution

The plates after the tests in the cone calorimeter are shown in Figure 1. The temperature evolution in the steel plates without protection was also measured to attain for the efficiency of this fire protection.

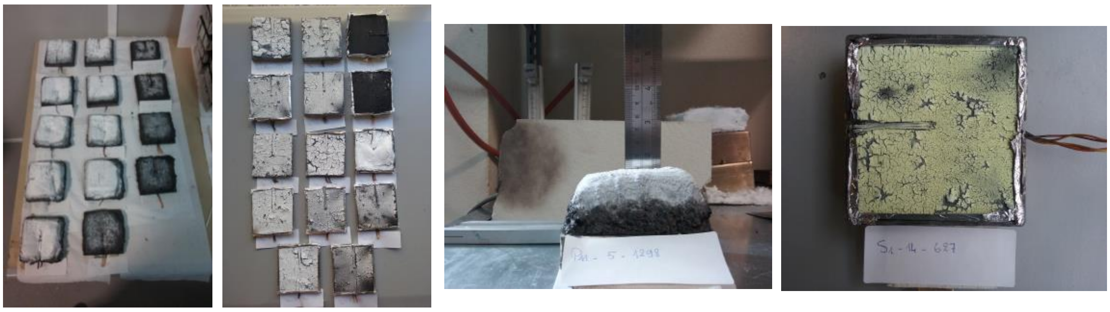

Figure 1: Coated steel plates before and after accelerated aging, with fixed thermocouples. Tested samples at 35 and at 75 KW.m$^{-2}$.

The temperature variation of different samples before the hydrothermal aging test is shown in Figure 2, for different plates with steel thickness equal to 5, 8 and 14 mm, submitted to heat fluxes of 35 and 75 KW.m$^{-2}$. The tested plates reach a steady temperature of 339 °C in test P14 and 479 °C in test P1 for 35 and 75 KW.m$^{-2}$, respectively.

For a specific period, the temperatures decrease with an increasing thickness of coating (DFT) and with the thickness of the steel plate. From Figure 2, and for a radiant heat flux of 75 KW.m$^{-2}$, it could be seen that the specimen P1 has the maximum temperature with a dry film thickness of 483 µm, while the minimum is for the test P11 with a maximum DFT about 1298 µm. For 35 KW.m$^{-2}$, the highest and lowest temperature are shown in P14 and P6 respectively, with dry film thickness of 602 and 1107 µm.

Compared to the specimens without protection, the steel temperatures of plates protected with intumescent coating decreases about 40 %.

After the specimens were subjected to an accelerated hydrothermal aging as described in the previous section, they were placed in the cone calorimeter. The tested plates reached a steady temperature of 560 °C in test S9 and 691 °C in test S8 for 35 to 75 KW.m$^{-2}$, respectively.

The measured temperatures obtained after the fire test are shown in Figure 3. It can be seen from the figure that, compared to specimens without aging, there is a sharp increase in steel substrate temperature after the accelerated hydrothermal aging test, where the temperature evolution of the steel plates with protection is very close to the plates without protection.

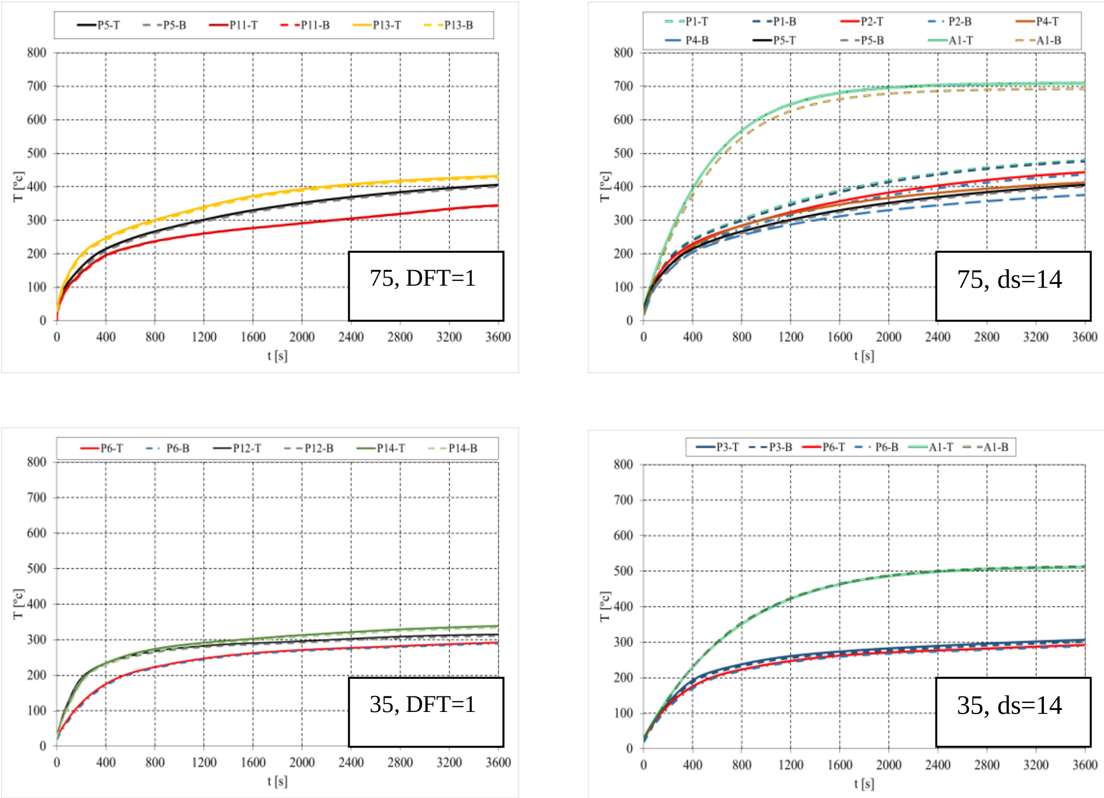


Figure 2: Measured temperature in the steel plates for a radiant heat flux of 35 and 75 kw.m$^{-2}$ before the hydrothermal aging test.

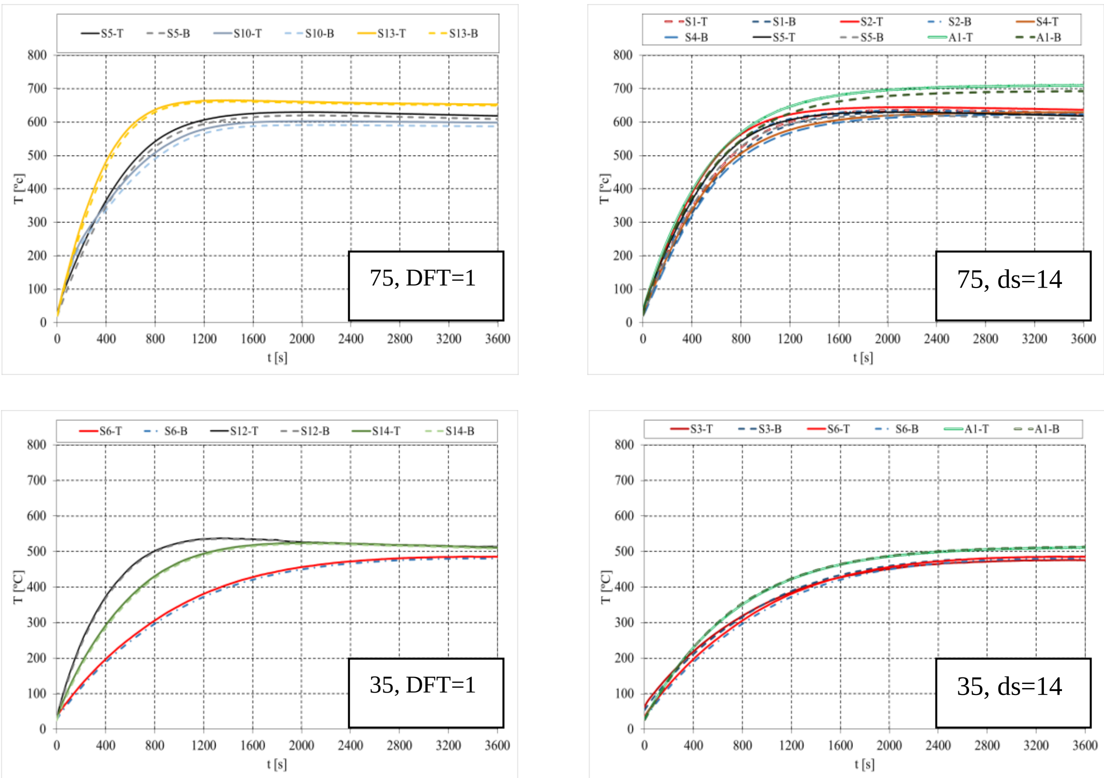


Figure 3: Measured temperature in the steel plates for a radiant heat flux of 35 and 75 kw.m$^{-2}$ after the hydrothermal aging test.

### 3.2. Intumescence development

Using discrete frames obtained from a digital camera during the tests, and by image processing techniques using Matlab, the intumescence development was measured over time. Figure 4 and Figure 5 present the intumescent expansion of the coating before the hydrothermal aging test for different thicknesses and radiant heat fluxes.

Higher intumescence may be observed in the samples P10 at 75 KW.m$^{-2}$ and P12 at 35 KW.m$^{-2}$ with a maximum thickness of 28.22 mm and 18.09 mm, respectively.

The figures show that the intumescence thickness is proportional with the dry film thickness (DFT) and inversely proportional with the steel thickness, depending also on the heat flux. The coating expansion increases with increasing thickness of the paint (DFT) and by decreasing the thickness of the steel plate, as can be seen with comparison of P6 and P12.

From Figure 4 it could be seen that there is a large difference in the intumescence development between the plates P1 and P2 while they have the same approximate characteristics. This is mainly due to the real dry film thickness since the specimen P2 has more thickness than P1 with a real dry film of 602 and 483 µm, respectively.

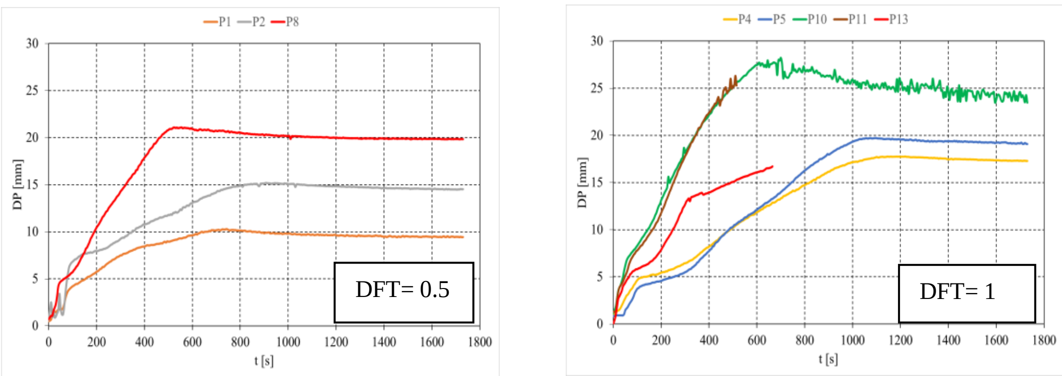


Figure 4: Intumescence expansion for a radiant heat flux of 75 KW.m$^{-2}$.

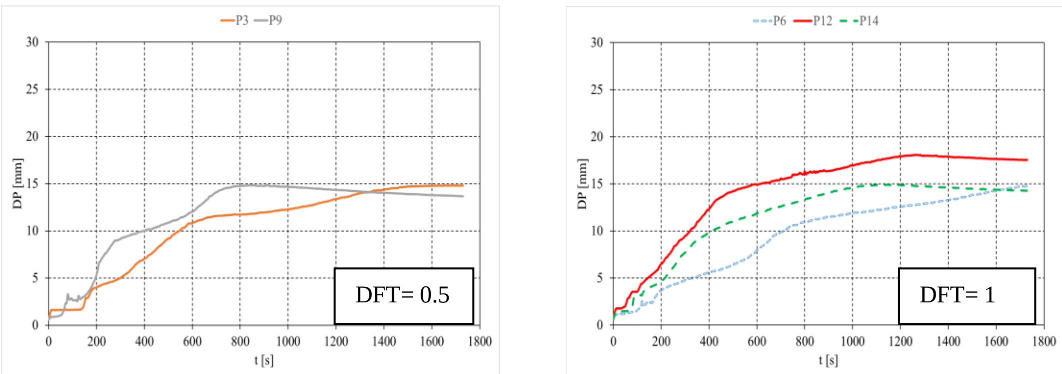


Figure 5: Intumescence expansion for a radiant heat flux of 35 KW.m$^{-2}$.

The expansion measurement of the specimen P11 stopped at time of 512 second because the intumescence char gone inside the cone calorimeter, making it impossible to continue measuring the expansion. Also, in case of the test P13 the camera moved at time of 665 seconds, so that, it was not possible to present the results after this time.

After the hydrothermal aging test and when the specimens were exposed to elevated temperatures from the exposed heat flux, the intumescent coating does not react, so there is no expansion in all the tests except in the specimen S10 that has a dry film of 1580 µm. Even for this sample, the final thickness of the intumescent char was very small, about 5 mm, see Figure 6.

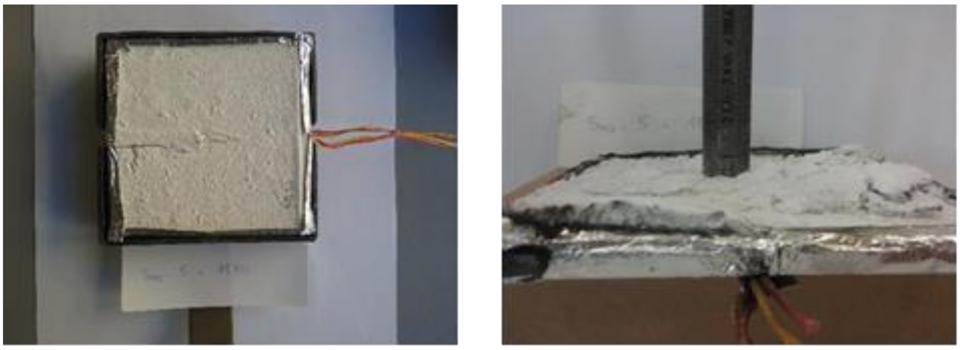

Figure 6: Final intumescent char thickness of specimen S10.

## 4. Conclusions

This paper presents the results of a series of fire tests on steel plates protected with an intumescent coating, performed in a cone calorimeter, to assess its performance when used in fire protection before and after 21 cycles of hydrothermal aging. This accelerated aging corresponds to 10 years in service according to exposure condition type Z1 from ETAG 018-part 2. The results have been presented in terms of the steel temperature and intumescence development.

The experimental tests show that the time to attain a specified temperature increases with increasing thickness of the coating (DFT) and by increasing the thickness of the steel plate.

Intumescent coating has considerable reduction in performance after hydrothermal aging test. For example the steel plate temperature of specimen S2 was increased by about 270 °C compared to the steel temperature of P2 with fresh intumescent coating for the same conditions and an exposure time of 30 min.

Intumescence development depends on the initial dry film thickness and on the incident heat flux, but the hydrothermal aging conditions damage its expansion capacity, leading to a drastic reduction of the intumescent coating fire insulation.

It should be pointed out that the tests were performed without the use of a top coat, and this final coat can provide additional resistance to the weathering conditions and influence the long term fire insulation capacity.

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